# In-Flight Calibration and Validation of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

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## ABSTRACT

Calibrated spectra acquired remotely as images allow determination of surface and atmospheric properties based on absorption and scattering expressed in the spectra. AVIRIS measures spectra as images in the solar reflected portion of the electromagnetic spectrum. To use these spectra for scientific research and applications, the calibration of the spectra must be known at the time of measurement in flight. To validate the calibration of AVIRIS in flight, an in-flight calibration experiment was performed for an over-flight on May 9, 1995 at Ivanpah Playa, California. In-situ measurements of the atmosphere and surface at a calibration target were measured. These measurements were used to constrain a radiative transfer code and predict the total upwelling spectral radiance incident at AVIRIS. This prediction was compared to the radiance measured by AVIRIS for the calibration target. An agreement of 96.5% was determined. The in-flight signal-to-noise was determined and shown to have more than doubled over the previous year.

## INTRODUCTION

Calibrated spectra acquired remotely as images, allow determination of surface and atmospheric properties, based on molecular absorption and constituent scattering characteristics. AVIRIS measures images of 11 by up to 100 km at 20-m by 20-m spatial resolution that consist of spectra from 400 to 2500 nm at 10 nm intervals. The spectral, radiometric and spatial characteristics of AVIRIS are calibrated in the laboratory (Chrien et al., 1990, 1996) prior to each flight season.

In order for AVIRIS to be used for scientific research and applications, the calibration of AVIRIS must be valid at the time spectra are measured from the ER-2 airborne platform. The operational environment inside the Q-bay of the ER-2 at 20 km altitude is different from that in the AVIRIS laboratory.

In-flight calibration experiment methodologies were developed for AVIRIS to confirm the accuracy of AVIRIS calibration in flight (Conel et al., 1988; Green and Gao, 1993; Green et al., 1988, 1990, 1992a). In these experiments the surface and atmosphere at a homogeneous ground calibration site are determined with in-situ measurements. These measurements are used to constrain MODTRAN3 (Berk et al., 1989; Anderson et al., 1995) radiative transfer code and predict the spectral radiance incident at AVIRIS. Comparison and analysis of the predicted and AVIRIS measured radiance are used to calibrate and validate the performance of AVIRIS in flight.

This paper describes the calibration target, measurements, analysis and results from the in-flight calibration experiment at Ivanpah Playa in 1995.

## MEASUREMENTS

On May 9, 1995, an in-flight calibration experiment was held at Ivanpah Playa, California, located 100 km south of Las Vegas, Nevada at 35.5150 degrees north latitude and

115.3990 degrees west longitude. Ivanpah Playa is a dry lake bed approximately 3 km by 15 km in size at 740 m elevation.

A calibration target was designated on a portion of the playa surface based on visually apparent homogeneity. The target was 40-m by 200-m (2 by 10 AVIRIS spatial resolution elements). The long axis of the target was oriented in the AVIRIS flight-line direction and demarked by blue tarps at each end of the target.

At the calibration target an automated sun photometer was used to collect data from sunrise through the time of the AVIRIS data acquisition. The sun photometer measures data at 370, 400, 440, 520, 620, 670, 780, 870, 940, and 1030 nm wavelengths. These calibrated measurements were used to derive instantaneous optical depths through the day as shown in Figure 1. Figure 2 shows the water vapor determined from 940 nm sun photometer measurements (Reagan et al., 1987, Bruegge et al., 1990). Some cirrus clouds affected the measurements around 10:00 a.m. local time.

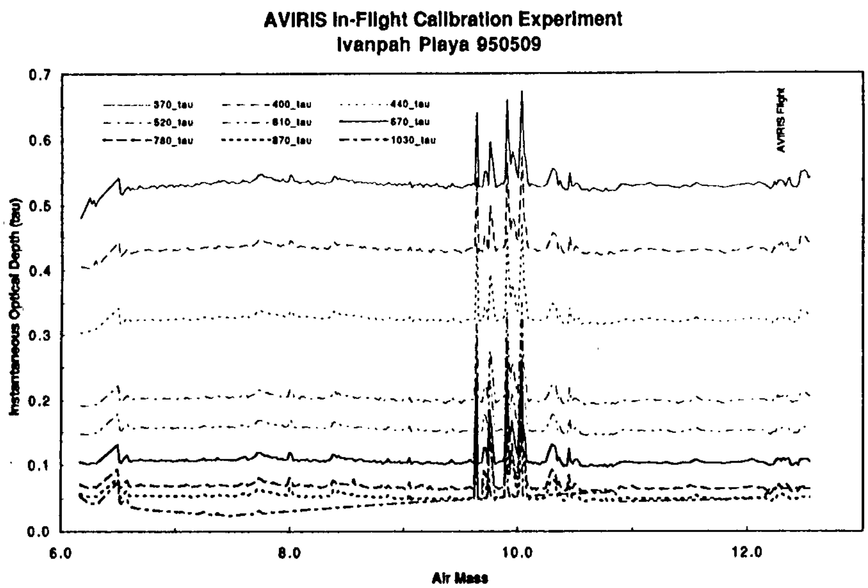


Figure 1. Derived optical depths of the non-water-vapor measurements of the sun photometer.

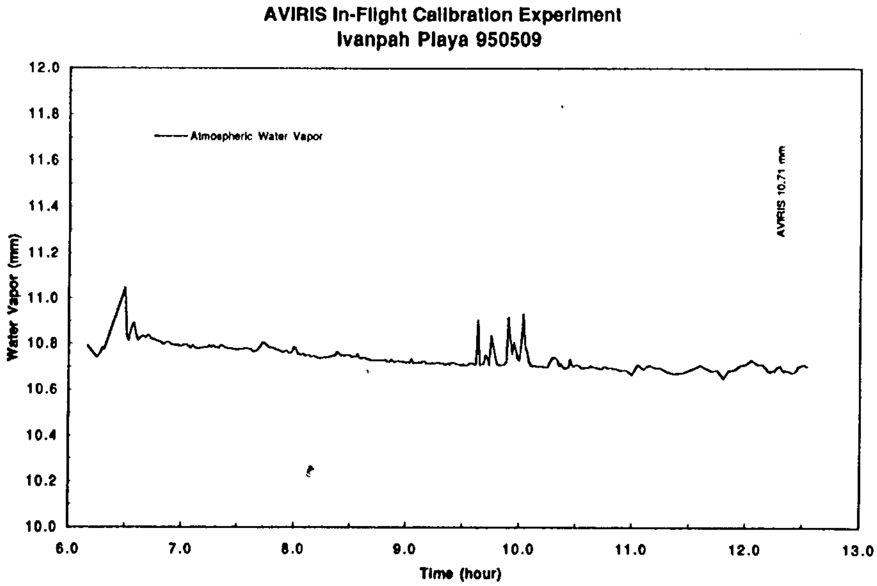


Figure 2. The water vapor abundance determined from the 940 nm sun photometer measurements.

During the time of the AVIRIS data acquisition, the surface spectral reflectance was measured using a field spectrometer that covers the AVIRIS spectral range. A total of 160 measurements were acquired. These measurements were evenly spaced over the target and averaged to determine the calibration target spectral reflectance as shown in Figure 3.

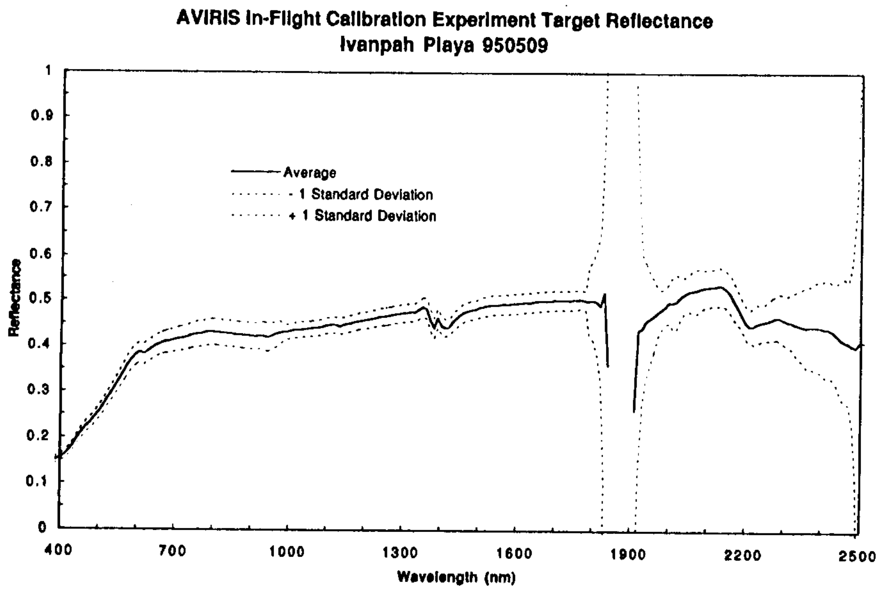


Figure 3. Calibration target spectral reflectance. The average and two standard deviations are shown.

At 19:19 hours UTC, AVIRIS acquired data over the Ivanpah Playa calibration target. Figure 4 shows an image of Ivanpah Playa from 647.7 nm wavelength. The enhanced image in Figure 5 shows the two dark blue demarcations on the left edge of the playa one third of the way from the top of the image. The uncalibrated AVIRIS spectra extracted from the calibration target are shown in Figure 6.

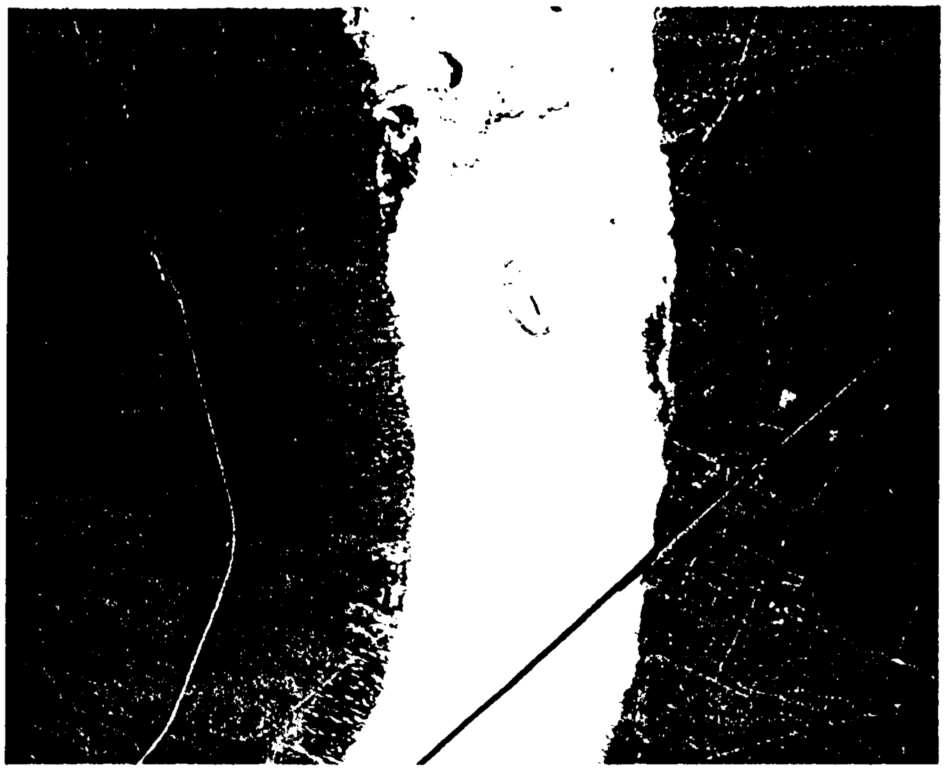

Figure 4. AVIRIS image of Ivanpah Playa from 647.7 nm.

Figure 5. Enhanced Ivanpah Playa image showing the two calibration target tarps on the left edge of the playa, one-third of the way from the top of the image.

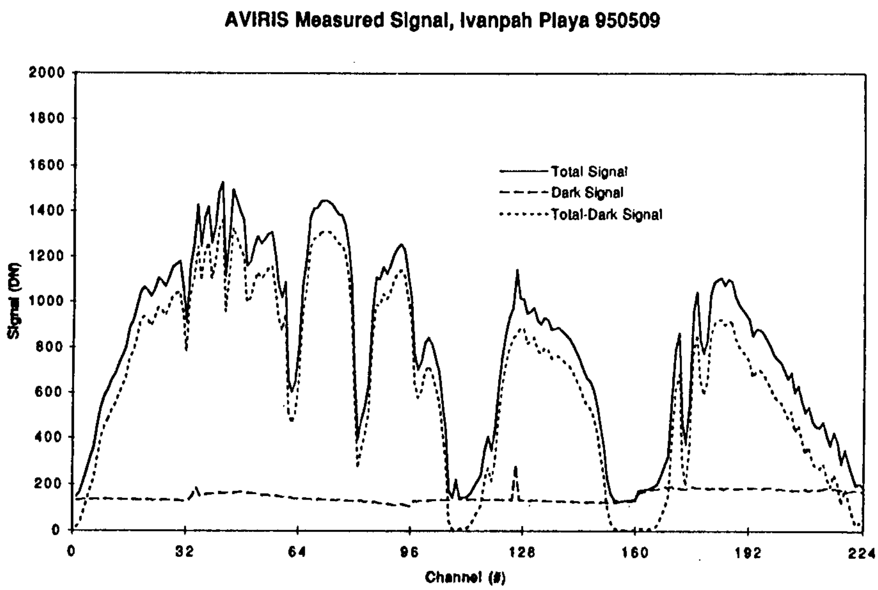


Figure 6. AVIRIS signal from the calibration target. The total signal, dark signal and dark subtracted signal are shown.

## ANALYSIS

Optical depths calculated at the time of the AVIRIS overpass were used to constrain the aerosol model used in MODTRAN3 for the calibration experiment. The measured and modeled optical depths are shown in Figure 7. These optical depths in conjunction with the surface spectral reflectance and atmospheric water vapor were used to constrain MODTRAN3 for the time of AVIRIS data acquisition. An updated exo-atmospheric solar irradiance spectrum (Green, 1993) was used in MODTRAN3. The MODTRAN3 predicted upwelling radiance for the calibration target is shown in Figure 8.

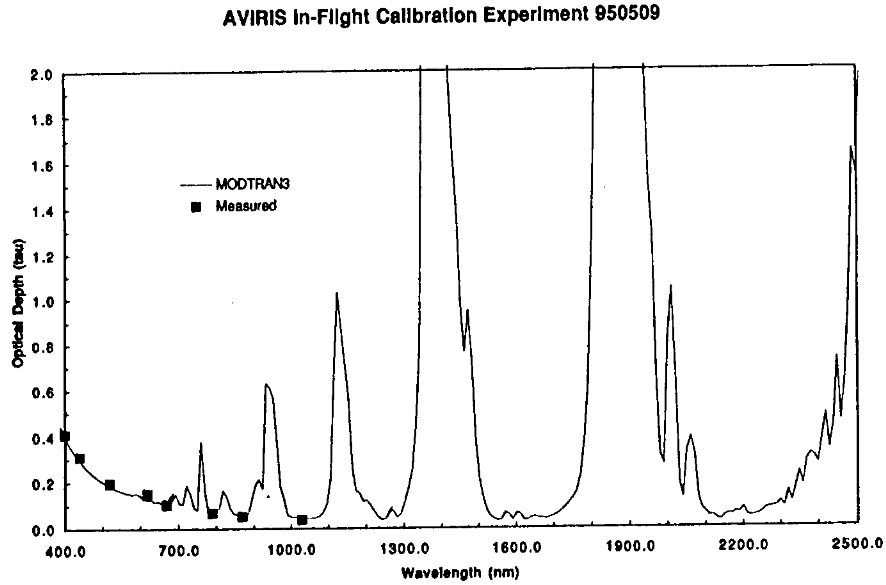


Figure 7. Measured and MODTRAN3 modeled optical depths of the Ivanpah Playa calibration experiment.

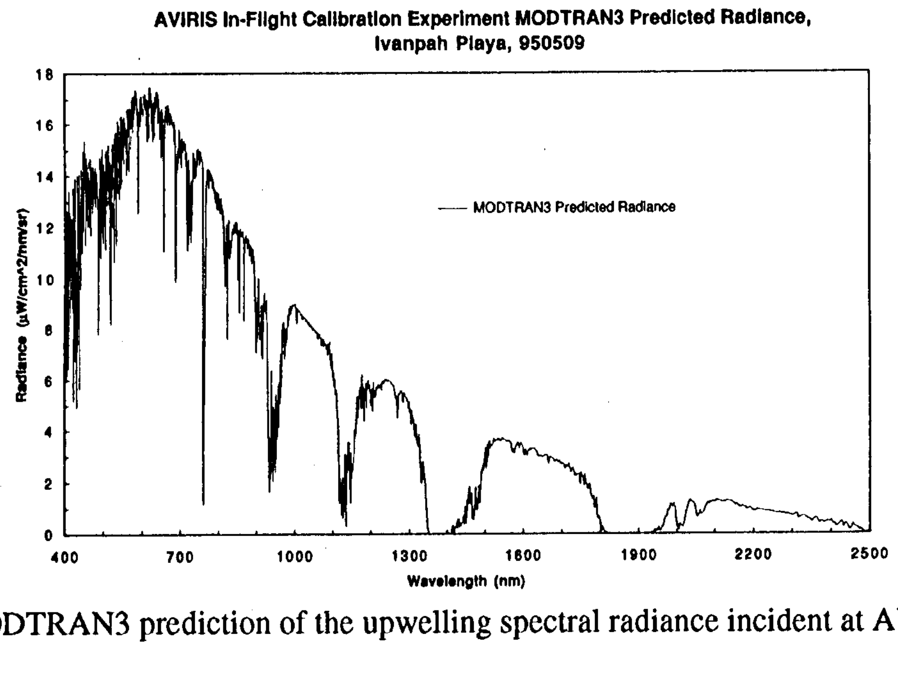


Figure 8. MODTRAN3 prediction of the upwelling spectral radiance incident at AVIRIS.

AVIRIS signal spectra were calibrated (Green et al., 1991) with the laboratory determined radiometric calibration coefficients and spectral calibration (Chrien et al., 1990; Chrien et al., 1996). AVIRIS on-board calibrator coefficients were derived as the ratio of the in-flight on-board calibrator signal to the signal at the time of laboratory calibration (Green 1993). These on-Board calibrator coefficients are shown in Figure 9 and were applied to the AVIRIS calibration target data.

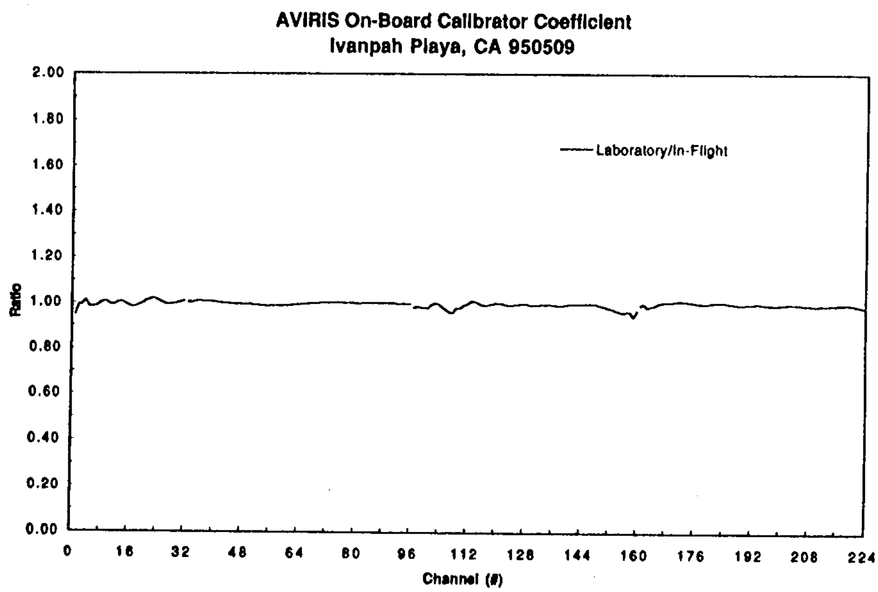


Figure 9. AVIRIS on-board calibrator coefficients. These coefficients compensate for small changes in AVIRIS performance from the laboratory to the in-flight condition.

## RESULTS

The MODTRAN3 predicted spectrum convolved to AVIRIS spectral response functions and the AVIRIS laboratory calibrated spectrums are shown in Figure 10. The average absolute agreement across the spectral range was 96.5 % for this experiment. The spectral regions of near-zero radiance at 1400 and 1900 nm were excluded. This result is improved over the 1994 in-flight calibration experiment result of 95.3 %. The disagreement was attributed to the in-situ measurements, the MODTRAN3 model, the AVIRIS instrument and to the calibration standards. Figure 11 shows the AVIRIS to MODTRAN3 ratio for the calibration target. In this ratio, disagreement occurs in the 400 nm region and near the atmospheric absorptions of water vapor, oxygen and carbon dioxide. These discrepancies are attributed to uncertainties in the MODTRAN3 model used in AVIRIS spectral calibration. Nevertheless, the agreement between the MODTRAN3 prediction and the AVIRIS measurement is within 4 % and this experiment initially validates the performance of AVIRIS in flight in 1995.

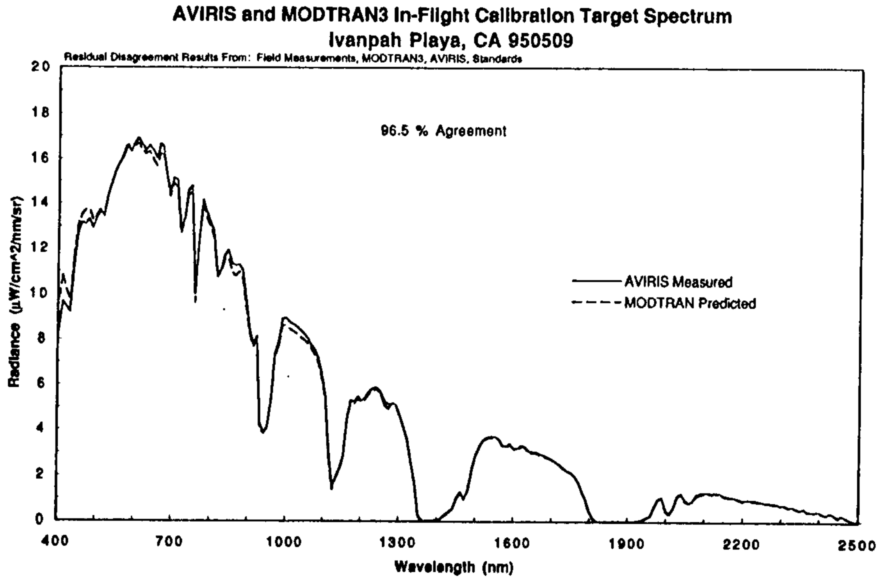


Figure 10. Comparison of the MODTRAN3 predicted and AVIRIS measured upwelling spectral radiance for the calibration target.

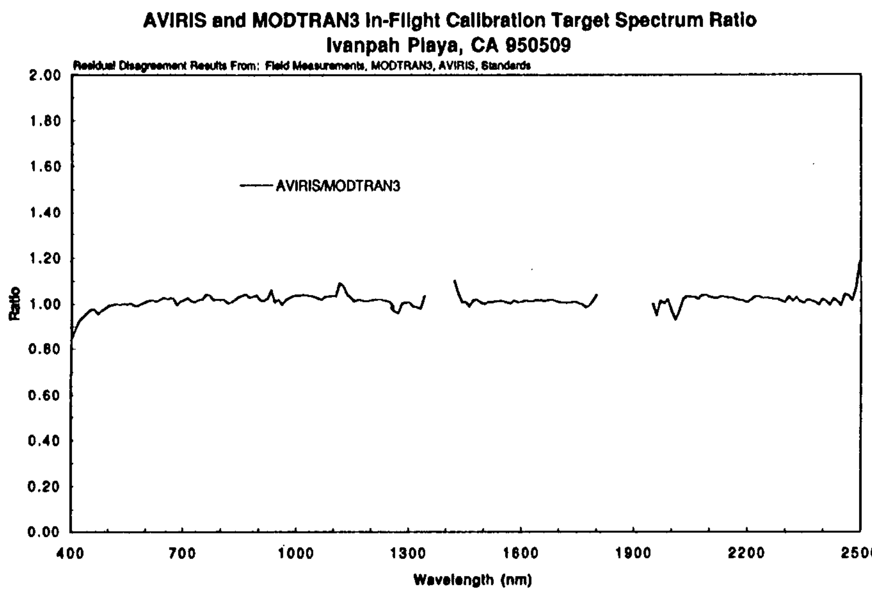


Figure 11. Calibration target ratio of AVIRIS to MODTRAN3.

In-flight radiometric precision (signal-to-noise ratio) was determined with data from this calibration experiment. Noise was estimated as the standard deviation of the dark signal measured at the end of each image line. The AVIRIS signal spectrum was extracted from the calibration target. The conversion factor of photons to signal was used to estimate the additional photon-noise for the calibration target. The photon-noise and dark-signal noise were root-sum-squared. The extracted signal was scaled to the AVIRIS reference radiance (Green et al., 1988) and divided by the noise to give the AVIRIS in-flight signal-to-noise ratio for 1995. This signal-to-noise is improved by more than a factor of two compared to that of 1994 as shown in Figure 12. AVIRIS signal-to-noise is greater than 500:1 over much of the spectral range. A calculation of noise-equivalent-delta-radiance was also performed for a dark target and is shown in Figure 13. The noise-equivalent-delta-radiance represents the precision uncertainty in radiance for each AVIRIS spectrum.

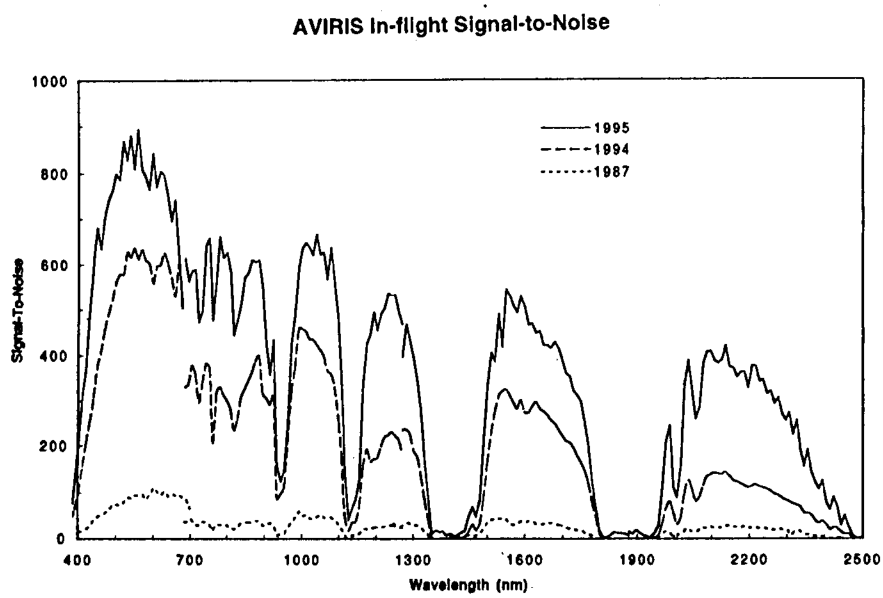


Figure 12. AVIRIS signal-to-noise for the 1995 in-flight calibration experiment.

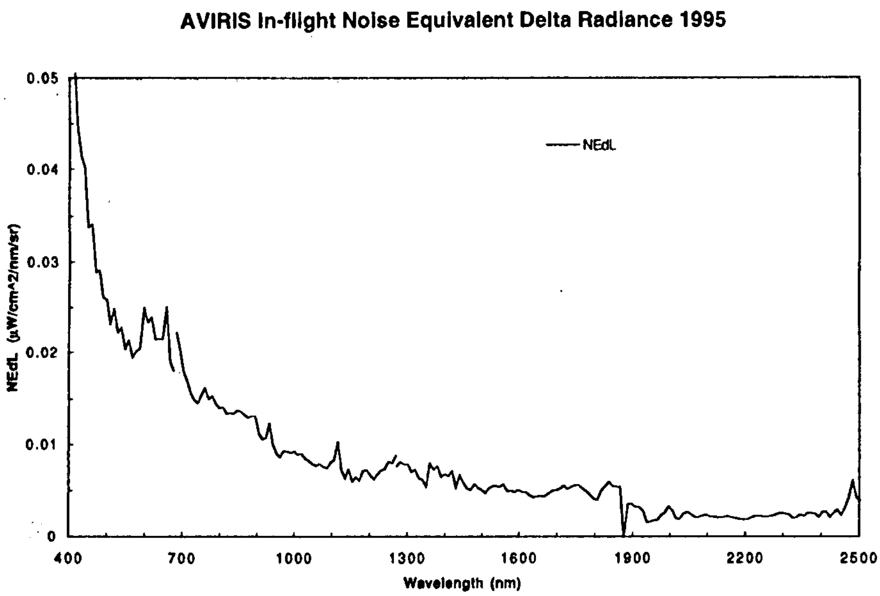


Figure 13. AVIRIS noise-equivalent-delta-radiance for 1995.

Additional analysis was performed to investigate the homogeneity of Ivanpah Playa at the AVIRIS spatial resolution. An image was produced of the ratio of the average to the standard deviation for all 10 by 10 spatial elements in the AVIRIS image. This image was produced from the sum of 20 AVIRIS channels in the visible band to suppress the influence of AVIRIS noise. The resulting image is shown in Figure 14. For 10 by 10 area at AVIRIS 20 by 20 m spatial resolution the homogeneity ranges from near zero to 500:1. At the calibration target, values of 100:1 are found. This analysis shows that relatively few in-situ measurements are required to characterize the surface of Ivanpah Playa. However, the surface is not homogeneous enough to estimate the signal-to-noise of AVIRIS which is greater than 1000:1 in portions of the spectrum.

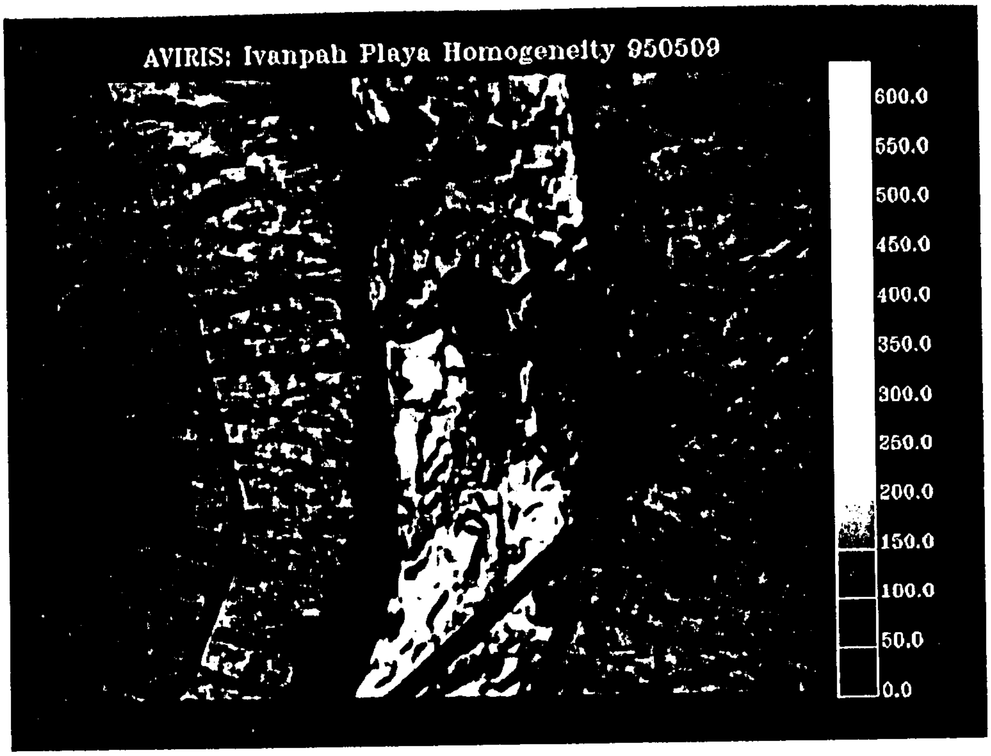


Figure 14. Ivanpah Playa homogeneity map May 9, 1995.

## CONCLUSION

An in-flight calibration experiment was held at Ivanpah Playa on May 9, 1995. Concurrent in-situ and AVIRIS measurements were acquired for a calibration target on the homogeneous playa surface. The MODTRAN3 radiative transfer code was constrained by the in-situ measurements to predict the total upwelling spectral radiance incident at AVIRIS. This prediction was compared with the AVIRIS measured (calibrated based on the laboratory and on-board calibrator coefficients) spectrum from the calibration target. A comparison showed 96.5 % agreement with the remaining 3.5 % attributed to the in-situ measurements, MODTRAN3, AVIRIS and the calibration standards. The in-flight precision of AVIRIS was assessed. Across the spectral range the AVIRIS precision was more than double that of any previous year. This experiment validates the calibration of AVIRIS in flight in 1995. The level of calibration and precision achieved supports use of AVIRIS for scientific research and applications that are based on the absorption and scattering characteristics of the atmosphere and surface expressed in the spectra.

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## ACKNOWLEDGMENTS

The majority of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. A portion of the work was performed at the Institute for Computational Earth System Science, University of California, Santa Barbara, California. We would like to express our appreciation for the efforts of the AVIRIS Team at the Jet Propulsion Laboratory, Pasadena, California.